Analysis Of the Application and Research Status of Key Technologies for Autonomous Positioning and Route Planning of Agricultural Machinery

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Abstract. Technologies such as route planning and autonomous positioning have been widely used in assisted driving and self-driving of the equipment like automobiles, construction machinery, and drones. At the same time, as agricultural machinery develops towards intelligence and unmanned operation, there is a rapid development in self-driving technologies of agricultural machinery in recent years. At present, autonomous positioning method used by self-driving agricultural machinery is mainly high accuracy satellite navigation system. However, the hardware costs of this method are relatively higher and this method relies heavily on good satellite signals, which limit its market promotion to a certain degree. As a result, navigation method that has high efficiency, low costs, and stable workability in harsh environments becomes the key to popularize self-driving technologies on agricultural machinery. Nowadays, as the costs of sensors such as binocular camera continue to decrease, methods like visual navigation and inertial navigation attract more and more attention, technologies in artificial intelligence such as machine learning and image processing also start to become efficient tools for self-positioning. This article mainly introduces the present situation and key technologies researches of autonomous positioning and route planning of agricultural machinery in recent years and discusses the future trend of self-driving agricultural machinery.

Keywords: Route planning; agricultural machinery; self-driving; autonomous navigation.

1. Introduction

In modern agriculture, agricultural machinery has become an essential part. It not only reduces manual workload but also increases production efficiency a lot. Take China as an example, from 2004 to 2020, the percentage of people taking up agriculture as their job falls from 46.90% to 22.87%, and the totally power of agricultural machinery rises from 6.4×10^8 kW to 1.1×10^9 kW. Although the labor force became smaller, the increasing level of agricultural mechanization led to a rapid rise in grain production [1]. Agricultural machinery has penetrated almost every processes. Corresponding machinery can cover the operation from cultivating, sowing, spraying to harvesting, and transporting. Harvesters that used for various vegetables also began to be used widely. It is the way on the development of modern agriculture that must be passed to develop agricultural machinery with all-round function, higher working efficiency, and lower costs.

As all professions develop towards intelligence and unmanned operation, agricultural machinery also needs to adapt to the new trend. In recent years, as the problem that rapid reduction and aging happened in agricultural labor force is becoming increasingly severe, intelligent agricultural machinery in China started to develop quickly. By the end of 2023, South China Agricultural University had begun the construction of 30 unmanned farms where self-driving tractors and harvesters were widely used in 15 provinces in China [2]. It can be said that intelligent agricultural machinery couldn't be separated from modern agriculture very early. This is because intelligent agricultural machinery can not only work automatically, but also employ neural networks to create a lookup table between humidity, temperature, and probability of precipitation, then help people make more reasonable decisions [3]. intelligent agricultural machinery lays a solid foundation for modern precision agriculture.

Autonomous positioning and route planning technologies are key technologies in intelligent agricultural machinery. Nowadays, there are plenty of research in autonomous positioning and route

planning of agricultural machinery. At present, the satellite navigation system is very mature, positioning function is achieved through satellite signals given by GPS or Beidou system. However, the costs of satellite navigation system are very high. As a result, visual navigation methods that combined with technologies like binocular cameras and image processing attract more and more attention. Inertial navigation that is widely used in aerospace also is used in agricultural machinery to provide navigation ability without satellite signals. Besides, many integrated navigation systems have appeared. They use complementary advantages of various approaches to achieve higher positioning accuracy and lower costs. These technologies are vital for agricultural machinery to realize self-driving.

At present, there are some problems in the promotion process of intelligent agricultural machinery in China. First, geographical conditions have many limitations. For example, the level of agricultural mechanization in mountainous area is under-developed. Agricultural machinery used in this kind of area must be simple to use, durable, and has stable performance. No one can guarantee that farmers in this area can operate intelligent agricultural machinery with higher technology [4]. Meanwhile, infrastructure for operation of agricultural machinery in certain area is incomplete, especially the network and satellite signals are very weak. This can't fulfill the demand for positioning and remote control of intelligent agricultural machinery while working [5]. So, developing autonomous positioning and route planning technologies of agricultural machinery that are reliable, cost-saving, and simple to use is the key to develop intelligent agricultural machinery.

This article mainly introduces the present situation and key technologies research of autonomous positioning and route planning of agricultural machinery in recent years and discusses the future trend of self-driving agricultural machinery.

2. Agricultural Machinery

2.1. Wheeled Agricultural Machinery

Wheeled agricultural machinery has a wide range. Up to now most of the agricultural robots are wheeled, including traditional agricultural machinery such as tractors and harvesters. Now, progress continues to be made in the research of wheeled agricultural machinery. For example, Nishimura et al developed a 4-wheel-steering robot mower to clear weeds in mountainous area. This robot used nylon rope as cutting tool. When compared to traditional metal blade, this method is safer because it can only cut soft things and can't damage people or properties severely. Meanwhile, this robot can operate mowing work in steep area and basically cover the working area, fulfilling the needs of actual application [6]. In the future, this method will develop towards automation, especially autonomous positioning of the robot and sensing potential obstacles in working environment.

2.2. Crawler Agricultural Machinery

Compared to wheeled agricultural machinery, crawler agricultural machinery has some unique advantages. First, because crawler agricultural machinery can make spin turning and center turning, its steering radius significantly surpassed wheeled agricultural machinery. Meanwhile, crawler agricultural machinery has more area in contact with the ground, which is beneficial for working in fields. So, the future of crawler agricultural machinery is very bright. There are also many research findings in crawler agricultural machinery. For example, Sun et al. proposed a hydraulic four-point adjustable lifting chassis for crawler harvesters. This method can balance the body on rough terrain and avoid rollover [7]. Aimed at crawler Rotary Tiller, Wu et al. Also proposed a method that used deep learning to simulate the operation of transmission. This method can shorten the time needed to develop new agricultural machinery and lower the development costs [8].

2.3. Agricultural Planes

The application of planes in agriculture mainly focuses on pesticide spraying. At present, the working width of using the sprayers mounted on tractors to spray pesticide is generally above 20m.

However, planes can spray pesticide overhead at a high speed and cover a wider width. So, whether it is a helicopter or propeller-powered small fixed-wing plane has been already used in pesticide spraying. These years, with the development of drones, large drones for pesticide spraying have been developed. Drones can also help tractors and harvesters to plan the best working route by taking aerial images. Zou et al. used MAVIC 2 drone made by DJI company to take aerial images of the fields, then used algorithm to identify weeds in the fields and provide accurate guidance for mowing. This method can save much pesticide. Less pesticide usage also protects the natural environment. Through accurate guidance, agricultural machinery can also plan the shortest route to complete the work, which can give rise to the working efficiency [9].

3. Autonomous Positioning Technology

3.1. Satellite Positioning

Because of the popularization of the satellite positioning system, it is more and more common to see agricultural machinery that uses satellite signals for positioning. Xinyi Liu used Beidou satellite in combine harvesters for route planning and positioning [10]. This method not only reduces the high costs caused by RTK equipment such as base station in previous ways, but also solves a problem that single block's precision is very low by using multi-positioning blocks. This method can be a good assistant that can send warnings when the harvester deviates from its predeterminate route for drivers. Meanwhile, it can be used to achieve autonomous driving during the working. During the experiment, the deviation between actual measured cut width and planned cut width was less than 1.19%. Considering this figure, it can be drawn the conclusion that this system can complete the real-time tracking of the harvester's operating route and react correctly to deviations [10]. Although there is still a certain gap in the maximum lateral deviation between auxiliary navigation equipment based on differential technology and this method, this method can fully utilize the role of the harvester driver, which can reduce the costs a lot. This is very beneficial for occupying the agricultural machinery market that is very sensitive to the costs at a high speed. However, there are still some limitations in this method. Firstly, the condition to use this way is too idealized. Harvesters may need to steer in working, but this method only consider the condition that run in a straight line. Moreover, this method needs good satellite signals for smooth operation, so the error can increase when the number of satellites is not enough and the signals are not good. Because of these limitations, this method can only be used in working conditions that don't need high precision. It has still a long way to go before it can be used in modern precision agriculture.

Satellite navigation system can not only be used in wheeled machinery, but also be utilized in crawler machinery which plays a large part in agricultural machinery for the reason that crawler machinery not only can achieve center steering and spin turning, but also is less likely to get stuck in harsh ground conditions when compared to wheeled machinery. As a result, it is very essential to develop the satellite navigation system for crawler agricultural machinery. Mu et al. proposed a route planning method for crawler agricultural machinery that based on Beidou satellite, as is shown in the fig1. In this method, navigation system first needs to acquire the latitude and longitude coordinates of the four corners of the fields through Beidou satellite, then gives the best working route while taking the size of machine and its working width into consideration [11]. Through experiment, the maximum error between the measurement point and the calculation point in this scheme is 0.09m and the average error is 0.046m, in other words, the precision can fulfill the needs of agricultural machinery which needs to be controlled accurately [11].

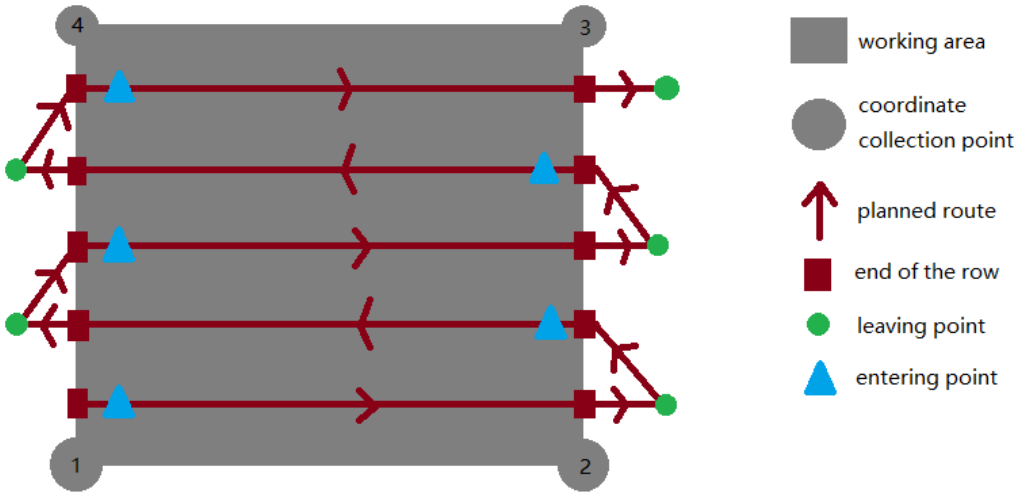


Fig. 1 the route of crawler agricultural machinery planned by satellite navigation system [11]

3.2. Visual Positioning

Visual positioning has also been widely used in agricultural machinery. Wu et al. proposed a route planning method that used computer vision technology in robot mower. In this method, CCD industrial camera is mainly used for image processing system to sense environmental information. Then, this method used texture features extraction method for gray level co-occurrence matrix to extract feature from the image. In this way the system can discover the obstacles existing in the environment. Through CDD* algorithm, robot mower can automatically bypass the obstacles in working area and plan the route in real time while considering the actual condition [12]. After using this method, the working area that robot mower can cover improved a lot. This meant the robot mower basically realized full coverage of the working area.

The combination of multiple navigation methods can lead to better performance. Since only using satellite signals for navigation may cause a certain amount of error and lack the ability to adapt to the actual scene, Jiahao Fu proposed a method that used Beidou satellite signals and machine vision together for navigation [13]. This method makes up for the disadvantage of satellite navigation in obtaining local information by using vision navigation system. Meanwhile, this method uses deep learning to process the real time image acquired in order to figure out the coordinates of navigation line. Experiments have proved that the positioning error of this method basically didn't exceed 4cm. The error can be even less than 2cm while operating in low speed. So, this method is very accurate.

3.3. Inertial Navigation

Although satellite navigation can realize high positioning precision, its costs is also very high. Zeqing Zhang used a comprehensive navigation system that mixed machine vision with inertial navigation to solve this problem. Compared to vision navigation, this method added inertial navigation to make the system achieve high accuracy while not relying on satellite signals [14]. When this method is used, working accuracy of self-driving transplanter is almost the same as the transplanter operated by a driver. It even has a gap about 1cm in average error of lateral deviation when compared to high precision satellite navigation. Although the convolutional neural network that this method used still has the space for optimization and the algorithm used for steering control has a long feedback period, satellite positioning can be used to provide the essential information to solve these problems. Also, this method can achieve higher positioning accuracy with lower costs while combined with a less accurate satellite positioning system.

3.4. Drone Assisted Navigation

As the drone becoming more and more developed, drone assisted navigation also started to be utilized in agricultural machinery. Gunchenko et al. suggested using drones to take aerial photograph

of the fields and processing these images with technologies such as neural network to identify the effective factors that are very significant for unmanned operation on the working route of self-driving harvesters, for example, crop harvest quantity, obstacle, planting area and so on. In this method, drones use ground control plants to identify their position and flight direction to take aerial photograph of the fields. As for larger fields, drones can divide the field into many zones to take photos and figure out panorama by certain software. This process can be carried on while the drones are flying. Then, RGB signals of images taken by camera carried by drones will be statistically processed to extract features of each zone. Next, neural network will calculate the theoretical harvest on the working route of self-driving harvesters to guide people to distribute machines and plan route in a more proper way [15]. This method can solve the situation that has many inputs because it uses neural network. When the number of input condition increases, this method can give a new solution only by making some small changes on the original data. As a result, it has high efficiency.

4. Route Planning Technology

4.1. Route Planning for Unstructured Scenes

A typical example of unstructured scenes is large agricultural machinery seeding scenes. In this scene, how we can cover the whole working area more economically and efficiently when the machine performs processes such as sowing, spraying and harvesting is a vital direction for research. The researches in the past generally exist some problems. First, the research range was too small, only the conditions that focus on small fields and have fewer routes were considered. Second, objects of the researches were very limited. Conditions involving multiple different specifications of agricultural machinery were not considered. Meanwhile, previous algorithms have a long run time, which means the ability to work in real time has great room for improvement.

So, Utamima et al. suggested using Fast Hybrid Algorithm (FHA) for route planning of agricultural machinery [16]. This method well solved the difficulty that route planning faces when the field is large and the number of the field required to be processed is high. While using this method, the distance that agricultural machinery runs without working can be reduced a lot, leading to a decrease in fuel consumption. Meanwhile, according to the results of the experiments, while solving 10 sets of route planning problems of agricultural machinery, Fast Hybrid Algorithm not only could figure out the best solution, but also had shorter run time than almost half of the algorithms mentioned in previous paper such as genetic algorithm and ant colony optimization. Fast Hybrid Algorithm can be used as a good foundation for route planning of agricultural machinery. In the future conditions that closer to reality can be studied, for example, adding limitations such as obstacles in the working route.

Except for Fast Hybrid Algorithm, Utamima et al. proposed another algorithm in 2022,which was called Evolutionary neighborhood discovery algorithm [17]. At that time, most researchers focused on the application of available algorithms and reality working conditions but Utamima et al. proposed an innovative and more advanced algorithm. Experiments have proved that compared with previous algorithms, this new algorithm can make the not-working distance of agricultural machinery reduced by 11.72% [17]. This means lower fuel consumption, which is very beneficial for sustainable development of agriculture.

4.2. Route Planning for Structured Scenes

Agricultural machinery working in structured scenes such as orchard faces totally different working environment compared with fields. Most orchards have trees planted neatly, so agricultural machinery can only pass through between trees, similar to a long and narrow corridor. In order to ensure agricultural machinery doesn't run into trees, agricultural machinery need to keep a distance with trees. At the same time, with regard to the machines that do the work like spraying pesticide, machines need to run along the central axis of the trees to make pesticide well-distributed to the trees on either side. Shen et al. made some advances in traditional A* algorithm and proposed a route planning method for orchards that based on cubic non-uniform B-spline curve [18]. This method used

Beidou satellite navigation system to get the coordinates and processed the environment of the orchard in real time through laser sensor to set up a map. Then, the algorithm figured out a curvature continuous working route according to the constraint such as steering delay and steering radius to make robot avoid stopping or steering suddenly while working. At last, robot sprayers carried out this route through tracking algorithm. According to the results of experiments, robot sprayers execute the scheduled route with high accuracy. Its average lateral error was $0.225\mathrm{m}$, standard deviation was $0.031\mathrm{m}$, which fulfilled the demand of the application of the robot [18].

5. Discussion

In the author's view, future developing trends of key technologies in autonomous navigation and route planning for agricultural machinery can be expressed as below:

1) Multiple source sensor integrated sensation: Through the combination of many kinds of navigation strategy, not only the ability to react in real time can be improved by complementing advantages, but also the system can rely less on single navigation method, which means the demand for hardware performance can be reduced. This is very important for costs reduction. Besides, as technologies such as artificial intelligence and machine learning become more and more developed, autonomous navigation and route planning of agricultural machinery will be integrated with artificial intelligence as well. This will reduce the difficulty of manual programming and control, which is better for market promotion.

2) Digital twins: With the continuous development of robotic technologies, nowadays industrial robots have achieved synchronization in reality and virtual environments. That is to say, operators can monitor the working state of robots on their computer screen in real time through setting up a virtual working environment in their computer. This technology will lead to a leap in route planning of agricultural machinery, because it not only brings more convenience for people to manage and control the machine, but also can be combined with offline programming technology to simulate working in advance to figure out the best parameters for working in reality fields. Meanwhile, when offline programming technology is used, working load of operators will be reduced a lot. Even one key operation can be achieved.

3) Multiple machines working together: Now, many processes of agricultural production need a lot of machines to work together. For example, harvesters need to unload in time when their grain storage becomes full. The time that harvesters wait for unloading is not-working time. If this period of time can be shortened, working efficiency of harvesters will improve a lot. Besides, harvesters need to go forward at the same speed of the trucks when unloading. At the same time, harvesters must keep a certain distance with trucks to avoid collision. How we can make multiple machines work together without collision and signals interference is a vital direction for research. This makes a higher demand for route planning. At present, although the Internet of Things has been mature enough to be utilized in information sharing between machines, the computer that agricultural machinery carries will process more information, leading to higher demand for calculating speed of the computer. This will cause a rise in costs. Remote computing may become a practicable way to solve this problem.

6. Conclusion

This article mainly analyses the current research situation and application development of the key technologies of autonomous positioning and route planning of agricultural machinery. First, the author discusses the background and future developing trends of the self-driving technologies of agricultural machinery. Then, autonomous positioning technologies of agricultural machinery are introduced in four aspects in a detailed way. Last, considering the actual needs of agricultural machinery operation, route planning technologies of agricultural machinery are overview analyzed separately based on structured scenes and unstructured scenes.

In the author's view, Beidou satellite navigation system used in agricultural machinery such as harvesters and transplanters is very mature and has many applications, however its high costs make its market promotion very difficult. Some progress has been made in experiment of vision navigation system combined with image processing and deep learning. Experiments have proved it could reach an accuracy that basically enough for working. Continuously decreased sensors costs such as binocular camera promotes the consecutive development of vision navigation as well. Meanwhile, many mixed navigation systems are making more and more progress. They increase navigation accuracy and reduce the costs by using many different navigation strategies together. The ability of autonomous navigation system to react in real time also, has been improved a lot, which means the system can sense obstacles in environment and plan a new route quickly. There are more working environments that autonomous navigation systems can be used either, regardless of broad fields, small orchards or steep mountainous area. As an important part on the way of the intelligent, unmanned development of agricultural machinery, autonomous navigation and route planning technologies of agricultural machinery will go on to be deeply integrated with new technologies such as artificial intelligence and lay a firm foundation for the development of precision agriculture and intelligent agriculture.

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